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# THE EFFECTS OF FUMIGANTS ON GRAIN DUST EXPLOSIONS

S.R. TAIT, R.G. REPUCCI and J.C. TOU

*Analytical Laboratories, Michigan Division, The Dow Chemical Company, Midland, MI 48640 (U.S.A.)*

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## Summary

The effects of three commercial fumigants on grain dust explosions were investigated under two laboratory conditions. Although the fumigants exhibit some flammable properties, the results of the test show that they do not increase the severity of grain dust explosions. In fact, in some cases, the fumigants actually suppressed the explosion.

## Introduction

A recent survey [1] reveals that grain elevator dust explosions have occurred at least 216 times from 1958—1977. During this period of time, there has been a steady increase in governmental regulations designed to prevent such incidents. The prevention of grain dust explosions is indeed a complex scientific, social, and economic task.

That grain dust explodes is a well-known fact. According to data from the United States Bureau of Mines, the index of explosibility of a mixed grain dust is about 9.2 times that of Pittsburgh coal dust. A comparison of explosion properties from a variety of common dusts, such as starch, soybean meal, etc., is summarized in the review [1]. Currently, concern has been expressed [1,6,7,8,9] on the effects of fumigants on grain dust explosion properties. The fumigants are added to the grains for insect control. The concern is essentially based on the following understandable possibilities:

Many of the formulated fumigants contain flammable components such as ethylene dichloride and carbon disulfide. It is conceivable that the presence of these flammable components may increase the ease of ignition of the dust particles and therefore promote the explosion hazard. On the other hand, is it not unreasonable to speculate that carbon tetrachloride, one of the major components in the commonly used fumigants and also a known fire retardant, may present an opposite effect and suppress a dust explosion ? In addition there are recent reports which suggest the possibility of synergistic behavior of methane gas in dust explosions when present with certain foreign additives in the grains. Anthony [2] demonstrated that polyvinyl chloride dust, known not to be explosive alone in a Hartmann tester, exploded in the presence of only 1.5%

TABLE 1

The compositions of the commercial fumigants investigated and the flammabilities of their formulated components

| | Flammability (% in air) | | | | |
|---|---|---|---|---|---|
| | Lower limit | Upper limit | Dowfume* | Vertifume* | Max Kill High Life* |
| Ethylene dichloride | 6.2 | 16 | 70 | — | — |
| Carbon tetrachloride | none | none | 30 | 82.9 | 82.8 |
| Carbon disulfide | 1.3 | 50 | — | 16.5 | 16.4 |
| Inert ingredient | — | — | — | 0.6 | 0.8 |

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methane in air. Singer et al. [3] also reported a similar synergistic effect of methane in lowering the minimum explosibility concentration of coal dust in air.

The effects of several commercial fumigants such as Dowfume* 75, Vertifume* and Max Kill High Life* on grain dust explosions were studied in a Hartmann tester. The compositions of the fumigants studied and the flammabilities of their formulated components are shown in Table 1. Their effects on the maximum pressure and its rate, minimum energy and minimum concentration were characterized. Because of the precision of the Hartmann technique, the significance of the data obtained was statistically evaluated.

## Experimental

The dust sample was obtained from the top of a local grain elevator. The sample is composed of an unknown mixture of corn, wheat, rye and oats.

The sample was first put through a 50 mesh sieve and then screened through a 200 mesh sieve of 74 microns. The dust particle size distribution, as analyzed with a HIAC Model PC-320 particle size analyzer manufactured by Pacific Scientific Instruments, California, is shown in Fig. 1. A portion of the grain dust obtained was dried in an oven at 75°C for 48 h followed by an additional 4 h of drying at 105°C in a glass cake pan. While drying at 105°C, the dust was stirred every 30 min to insure its uniformity and complete dryness.

The recently proposed ASTM test procedure using the Hartmann Dust Explosion tester was employed with the exception that a hot coiled wire ignition source was used instead of the continuous spark suggested in the procedure. The coiled wire was 24 turns of 24 gauge Nichrome wire and was heated with 110 V power. The advantage of this choice has been discussed elsewhere

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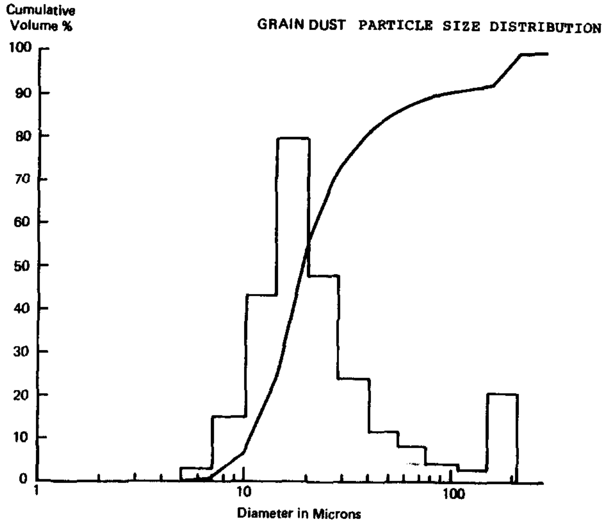


Fig.1. Grain dust particle size distribution.

[4]. The performance of the Hartmann tester was checked each day before and after the sample run against Lycopodium powder, and the screened grain dust.

The pressure and the pressure rate during an explosion in the Hartmann tester were monitored with a fast response (1 $\mu$s), Piezotronics Model 113A24 pressure transducer connected to a Tectronix Oscilloscope and to a Model-45A peak meter manufactured by Piezotronics, New York. The maximum pressure and the maximum pressure rate were obtained from a series of experiments with different grain dust concentrations.

The determination of the minimum energy, required in a static spark to ignite the dust cloud at the concentration of the maximum pressure and the maximum pressure rate, was made from the discharge of selected capacitors of 0.001, 0.01, or 0.1 mfd which had been charged to a known potential by a standard high voltage power supply across 1/4" air gap. The discharge was initiated 0.3 s after the dust was dispersed with 100 p.s.i. air into a clear, heavy, glass Hartmann tube. The ignition of the dust was observed by the bursting of the paper diaphragm at the top of the tube. The experiment was repeated several times above and below the point of ignition with varied amounts of energy. The minimum energy was finally determined when 0.01 mfd was used.

The experiments for determining the minimum explosion concentration limits were carried out also in the Hartmann tester with the pressure transducer attached to it. The minimum concentrations were determined at the minimum pressure rise. The coiled wire was used as an ignition source.

The effects of fumigants on the grain dust explosion were determined on the dried grain dust in order to simulate a "worst case" situation. The addition of fumigants to the grain dust was accomplished by the following two ways:

The grain dust was weighed to 1 mg and loaded to the Hartmann tester. Five drops of a fumigant were added through a hole of about 0.028″ in a coned Whatman# 4 filter paper from a Curtin 5 3/4″ transfer pipet. After the fumigant had been evaporated, the paper was removed, the tube sealed, and the standard testing procedure then followed.

The second way of preparing the fumigated grain dust samples was accomplished by mixing the dried grain dust with the recommended amounts of fumigant. The mixtures were then rolled for 48 h in a sealed container. Care was taken in the process of sample handling to minimize losses of the fumigants.

## Results and discussion

The precision of the maximum pressure and the maximum pressure rate determined in the Hartmann dust explosion tester is shown in Table 2 for the undried grain dust and Lycopodium at their maximum pressure rate concentrations of 0.24 oz/ft$^3$ and 0.56 oz/ft$^3$ respectively. The relative precisions

TABLE 2

The precision of the maximum pressure and the maximum pressure rate determined in Hartman dust explosion tester

| Experiment | Grain dust before drying (0.24 oz/ft$^3$) | | Lycopodium (0.56 oz/ ft$^3$) | |
|---|---|---|---|---|
| | Max. press (p.s.i.) | Max press. rate (p.s.i./s) | Max press. (p.s.i.) | Max. press. rate (p.s.i./s) |
| 1 | 76 | 2580 | 69 | 6435 |
| 2 | 73 | 2714 | 104 | 7045 |
| 3 | 65 | 2174 | 99 | 5926 |
| 4 | 73 | 1962 | 108 | 7692 |
| 5 | 63 | 2391 | 116 | 8167 |
| 6 | 66 | 1500 | 96 | 4786 |
| 7 | 77 | 2354 | 94 | 6045 |
| 8 | 67 | 2580 | 94 | 5833 |
| 9 | 68 | 2016 | 95 | 5882 |
| 10 | 74 | 2260 | 90 | 5231 |
| 11 | 62 | 1683 | 102 | 5458 |
| 12 | 60 | 1434 | 89 | 5167 |
| 13 | 75 | 2386 | 113 | 7876 |
| 14 | 69 | 1608 | 116 | 7600 |
| 15 | 70 | 2100 | 111 | 5250 |
| 16 | 70 | 1700 | 120 | 7381 |
| 17 | 64 | 1550 | 102 | 5375 |
| 18 | 75 | 2019 | 116 | 5133 |
| 19 | 63 | 1618 | 113 | 8222 |
| 20 | 62 | 1775 | 102 | 4750 |
| Average ± S.D. | 69 ± 6 | 2000 ± 360 | 100 ± 12 | 6300 ± 1100 |

$(\bar{\sigma}/\bar{\chi})100\%$, where $\sigma$ is the standard deviation and $\bar{\chi}$ the average value, are about 18% for both cases. The average value of the maximum pressure rate for Lycopodium was found to be 6300 p.s.i./s. The data indicate that for a reliable comparison, it is necessary to evaluate the data statistically. One experiment is definitely not sufficient to define the significance of the observation. The pressure data reported in this paper are the results from the statistical average of twenty experiments. As described in the experimental section, the Hartmann bomb was also standardized with the undried grain dust and Lycopodium each day before and after the designed experiments were done. No statistically significant difference was observed before and after the designed experiments. Part of the data are shown in Table 3. Statistically speaking, the average values are very close to those shown in Table 2.

In addition to the experimental uncertainty in the measurement of the maximum pressure and the maximum pressure rate, the concentrations at these maxima are usually not very well defined. This has been revealed in the early study [5]. Therefore, we have characterized the effects of the fumigants on the maximum pressure and maximum pressure rate at the same concentration as that, 0.24 oz/ft$^3$, determined for the grain dust before being dried.

In order to simulate a "worst case" situation, the basis chosen for comparison is the dried grain dust. The data are summarized in Table 4. The statistical "t" test was used to evaluate the significance of the effect of the fumigants on the dried grain dust explosions. As shown in Table 4, the statistical differences were evaluated at three confidence levels, 90%, 95%, and 99%.

The maximum pressure rate of the dried grain dust is significantly higher than that before being dried. However, the maximum pressures generated are about the same for both cases.

Generally speaking, there is no well-defined trend, which can be drawn

TABLE 3

The maximum pressure rates of the grain dust before drying and Lycopodium in a Hartman dust explosion tester

| Day | Grain dust before drying (0.24 oz/ft$^3$) | Lycopodium (0.56 oz ft$^3$) |
|---|---|---|
| 1 | 1899 | 7216 |
| 2 | 1921 | 5877 |
| 3 | 2090 | 7050 |
| 4 | 1974 | 6191 |
| 5 | 1821 | 6780 |
| 6 | 2050 | 7014 |
| 7 | 1744 | 5422 |
| 8 | 1925 | 6888 |
| 9 | 1800 | 7062 |
| 10 | 2077 | 5729 |
| 11 | 2045 | 6245 |
| Average | 1900 ± 120 | 6500 ± 520 |

TABLE 4

The grain dust explosion and the effect of fumigants

| Sample | Max press. (p.s.i.)** | Max press. rate (p.s.i./s) | Conc. at max. press. rate (oz/ft$^3$) | Min. energy (J) | Min. conc. (oz/ft) |
|---|---|---|---|---|---|
| Grain dust before drying | 70 ± 6 | 2000 ± 360 | 0.24 | — | — |
| Dried grain dust | 78 ± 4 | 4000 ± 570 | 0.24 | 0.180 | 0.050 |
| Dried grain dust + 5 drops of Dowfume* 75 | 77 ± 4 | 4400 ± 630 [1] | 0.24 | 0.125 | 0.046 |
| Dried grain dust + 5 drops of Max Kill High Life* | 69 ± 5 [3] | 3300 ± 610 [3] | 0.24 | 0.125 | 0.066 |
| Drained grain dust + 5 drops of Vertifume* | 82 ± 4 [2] | 4800 ± 750 [3] | 0.24 | 0.125 | 0.056 |
| Dowfume* 75 dried grain dust (6 gals/ 1000 bushel) | 56 ± 3 [3] | 2600 ± 280 [3] | 0.24 | 0.125 | 0.054 |
| Max Kill High Life*/ dried grain dust (6 gals/1000 barrels) | 80 ± 4 | 3700 ± 590 | 0.24 | 0.125 | 0.049 |
| Vertifume*/dried grain dust (6 gals/ 1000 barrels) | 81 ± 3 | 4000 ± 400 | 0.24 | 0.125 | 0.052 |

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**Average ± 1 standard deviation. Statistical analysis indicates that it is a significant difference from the control, the dried grain dust, at the (1) 90%; (2) 95%; or (3) 99% confidence level.

from the result shown in Table 4, on the effects of fumigants on the maximum pressure and the maximum pressure rate. Statistically, the maximum pressure and the maximum pressure rate generated in the cases of the dried grain dust with 5 drops of Max Kill High Life and mixed with Dowfume 75 in a proportion of 6 gallons/1000 bushels are definitely lower than those in the dried grain dust with 5 drops of Vertifume and no significant effect was observed in the rest of the cases. As shown in Table 1, the compositions of Max Kill High Life and Vertifume are very similar with minor difference in the inert ingredients. It would be expected that the effect on the grain dust explosion should be very similar. The maximum pressure and rates of the dried grain dust mixed 6 gallons/1000 bushels with the above two fumigants are almost identical, however, significant differences were observed from the 5 drop addition procedure (Table 4). The reason leading to this observation is not known.

The minimum energy of ignition of the dried grain dust with the fumigants added is lower than that for the dried grain dust by itself. The exact difference was not determined since no values were checked between 0.180 and 0.125 J. It is believed that the reduced ignition energy does not constitute a significant increase in the hazard. Historically, the known ignition sources in a grain elevator have very large energies such as welding, open flame, and electrical failures. Less than 2% may have been caused by static charges [1].

As indicated in Table 4, four out of the six cases studied show that the minimum concentrations are higher than that of the dried grain dust.

## Conclusion

In conclusion, no statistically uni-directional effects of the fumigants on the maximum pressure, the maximum pressure rate, or minimum concentration was observed under the present laboratory controlled conditions. In fact, in some cases, the fumigants actually suppressed the explosion.

The data indicate that the presence of the fumigants did lower the minimum ignition energy from 0.180 J to 0.125 J. However, it is believed that the reduced ignition energy does not constitute a significant increase in the hazard, since ignition sources encountered in a grain elevator typically have much higher energies than 0.125 J.

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